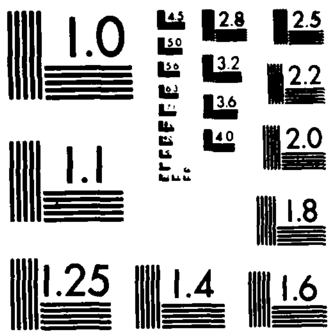
AD-A192 127 ELECTROMAGNETIC FIELD PENETRATION INTO STRUCTURES(U) 1/1
SYRACUSE UNIV NY DEPT OF ELECTRICAL AND COMPUTER
ENGINEERING R F HARRINGTON 10 MAR 88 ARO-21378.13-EL
UNCLASSIFIED DAAG29-84-K-0078 F/G 20/3 NL



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

UNCLASSIFIED   DTIC FILE COPY   MASTER COPY - FOR REPRODUCTION PUBLIC PURPOSES   (2)

SECURITY CLASSIFICATION OF THIS PAGE

AD-A192 127

REPORT DOCUMENTATION PAGE

DTIC ELECTE APR 1 1 1988 D

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) ARO 21378.13-EL
6a. NAME OF PERFORMING ORGANIZATION Syracuse University; 6b. OFFICE SYMBOL (If applicable) ECE	7a. NAME OF MONITORING ORGANIZATION U. S. Army Research Office
6c. ADDRESS (City, State, and ZIP Code) Dept. of Electrical and Computer Engineering, Syracuse, NY 13244-1240	7b. ADDRESS (City, State, and ZIP Code) P. O. Box 12211, Research Triangle Park, NC 27709-2211
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U. S. Army Research Office; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAG29-84-K-0078
8c. ADDRESS (City, State, and ZIP Code) P. O. Box 12211, Research Triangle Park, NC 27709-2211	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO

11. TITLE (Include Security Classification)
Electromagnetic Field Penetration into Structures

12. PERSONAL AUTHOR(S) Roger F. Harrington

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 7/1/84 TO 12/30/87	March 10, 1988	9

16. SUPPLEMENTARY NOTATION
The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Apertures, Electromagnetics, Penetration into Structures. Method of Moments;

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report summarizes the work done on electromagnetic field penetration into structures during the period July 1, 1984 to December 30, 1987. An introductory section states the purpose and general findings of the research. The next section lists the research reports issued, with the abstract of each report. The third section lists the papers published in journals, with the abstract of each paper. The fourth section lists the oral papers given. The final section lists the persons who worked on the project, and degrees awarded.

Keywords.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code); 22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR   83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

I. OUTLINE OF RESEARCH FINDINGS

An integral equation for the change in the aperture admittance matrix for a body of finite extent from that for the same aperture in a conducting plane has been derived. This is particularly useful in cases for which Bethe-hole theory has been used in the past. Computations indicate that the behavior of an aperture in a body of finite size may differ greatly from that for the same aperture in a conducting plane. The use of aperture polarizabilities for apertures in conducting planes is not sufficient to predict their behavior in finite bodies. An oral paper on this topic was given at the URSI 1985 North American Radio Science Meeting, June 1985. The abstract of this paper is given in Section IV.

An investigation of the coupling of electromagnetic energy to bodies within a finite structure perforated by an aperture has been made. In general, this problem can be formulated in terms of an aperture admittance matrix for the aperture in the structure, an impedance matrix for the body within the structure, and a pair of coupling matrices for aperture-to-body coupling. The aperture admittance matrix is the same as for the empty cavity. The body impedance matrix is the same as for the body in the structure with no aperture. The coupling matrices account for all interactions between the aperture and body. Application of this theory to two-dimensional problems has been made.

A pseudo-image method for analyzing apertures in a body of finite extent has been developed. This results in the aperture admittance being expressed as the admittance of the same aperture in a half-space plus a correction term. The singular behavior of the aperture fields and currents is accounted for by the correction term. In many cases, such as near interior resonances, this correction term is large in magnitude. The theory has been applied to two-dimensional problems, such as apertures in cylindrical structures of arbitrary cross section. The problems treated may have interior boundaries and media which are different from the exterior boundaries and media. They can therefore be used to model vehicles having thick walls and/or interior rooms.

As an alternative method for calculating the field penetration through an aperture into a conducting body of finite extent, a modal approach has been considered. In this case the internal aperture admittance is expressed as a summation over all cavity modes. We have experienced difficulties summing infinite series which are very slowly convergent. This is the same trouble that has hampered previous investigators of three-dimensional cavity problems. We have looked into ways of finding analytic sums for such series, but are not very successful. So far we have been using techniques similar to those of D. Seidel (IEEE Trans., MTT-26, 1978, p. 908) to estimate the limit points of the infinite series. A promising technique appears to be a combination of the non-modal and modal formulations. All modes not near resonance might be accounted for by an integral equation method, and modes near resonance by exhibiting them separately as cavity modes.

Work on Electromagnetic field penetration into three-dimensional conducting bodies of arbitrary shape, with apertures of arbitrary shape, and containing arbitrary matter, has been started. This problem is considerably more difficult than the two-dimensional problem on which we have expended our major effort. We have attempted to develop a general computer program which calculates the currents on all bodies and the fields internal and external to the cavity. The approach used is that outlined in the proposal "Electromagnetic Penetration into a Cavity of Arbitrary Shape Enclosing Lossy Dielectrics and Perfect Conductors of Arbitrary Shape," submitted to ARO in March 1987.

II. RESEARCH REPORTS ISSUED

1. Joseph R. Mautz and R. F. Harrington, "Electromagnetic Transmission through a Slot in a Perfectly Conducting Plane," Interim Technical Report No. 1, TR-84-9, December 1984.

ABSTRACT: When a plane wave is incident on a slot in a perfectly conducting ground plane of infinite extent, three quantities of interest are the tangential electric field in the aperture, the transmission coefficient, and the scattering cross section. It is assumed that the tangential electric field in the aperture is transverse to the slot axis and depends only on the coordinate along the slot axis. A computer program is presented to calculate the tangential electric field in the aperture, the transmission coefficient, and scattering cross section. This program is described and listed. Sample input and output data are included for the convenience of the user.

2. J. R. Mautz, X. Yuan, and R. F. Harrington, "Electromagnetic Scattering from a Slotted TM Cylindrical Conductor by the Pseudo-Image Method," Interim Technical Report No. 2, TR-85-3, September 1984.

ABSTRACT: The generalized network formulation for aperture problems is a well-established method for determining electromagnetic scattering from an aperture perforated conducting surface. This method is easily implemented for an aperture in an infinite conducting plane because the field due to a sheet of magnetic current $\underline{M}$ on the surface of a conducting plane is, by the method of images, the field of $2\underline{M}$ in free space. The method is more difficult to implement for an aperture in a curved conducting surface because the electric current induced by $\underline{M}$ on this surface can not be accounted for by imaging. This current must be calculated. Its calculated values are often inaccurate and so are those of the aperture field. In the present work, a more accurate aperture field is obtained for a TM curved cylindrical surface by means of the generalized network formulation for aperture problems in conjunction with a new method called the pseudo-image method.

3. Hu Zhenya and R. F. Harrington, "Electromagnetic Penetration through a Slot into a Rectangular Waveguide," Interim Technical Report No. 3, TR-85-4, October 1985.

ABSTRACT: Electromagnetic penetration into a matched rectangular waveguide through a longitudinal slot in a conducting plane is considered. The problem is divided into two parts, one in half space and another inside the waveguide, by use of the equivalence principle as described in reference [1]. The resultant equations are the same as those descrived in reference [2]. The only difference is that the excitation vector is changed from an incident wave inside the waveguide to an incident plane wave in half space. The magnetic current over the slot is obtained from the solution of the matrix equations. The electromagnetic penetration into a matched rectangular waveguide and the electromagnetic reradiation into half space through a slot are computed from the equivalent magnetic current over the slot. The computed results show that a plane wave at normal incidence and a resonated slot near the side of the waveguide broad wall allow orders of magnitude greater power to penetrate into the waveguide than when the slot is not resonated.

4. J. R. Mautz and R. F. Harrington, "Computer Programs for Electromagnetic Scattering from a Slotted TM Cylindrical Conductor by the Pseudo-Image Method," Interim Technical Report No. 4, TR-85-5, November 1985.

ABSTRACT: Two computer programs are described and listed. Suppose that an infinitely thin perfectly conducting cylindrical surface with an infinitely long but narrow gap is illuminated by a TM plane wave. The first program uses two different methods, the methods of solution with and without pseudo-image, to calculate the tangential electric field in the gap. The second program uses the Fourier series method of solution to calculate the tangential electric field in the gap for the special case in which the surface is a nearly complete circular cylindrical shell and the TM plane wave propagates perpendicular to the plane of the gap. To enable the user to verify that they are running correctly, both programs are provided with sample input and output data.

5. X. Yuan, R. F. Harrington, and J. R. Mautz, "The Pseudo-Image Method for Computing Electromagnetic Field Penetration into a Cylindrical Cavity, TM Case," Interim Report No. 5, TR-86-1, May 1986.

ABSTRACT: A solution for the electromagnetic coupling through an aperture in an arbitrarily shaped perfect conductor is obtained by the generalized network formulation for aperture problems in conjunction with a new method called the pseudo-image method. The theory developed is applied to a TM curved cylindrical surface with a narrow or a wide slot. The field in an aperture in a circular cylindrical surface is calculated by the pseudo-image method, by a method without a pseudo-image, and by a method in which only an electric current is used. The aperture field calculated by the pseudo-image method is the most accurate because it agrees best with a Fourier series solution.

6. J. R. Mautz and R. F. Harrington, "Electromagnetic Penetration into a Conducting Circular Cylinder through a Narrow Slot, TM Case," Interim Technical Report No. 6, TR-86-4, December 1986.

ABSTRACT: A procedure is presented for calculating the electromagnetic field in the vicinity of an infinitesimally thin conducting circular cylindrical shell with an infinitely long slot illuminated by a TM plane wave. This field is the short-circuit field plus the field due to the slot. The short-circuit field is the field that would exist if there were no slot. The field due to the slot stems from the axial electric field in the slot. Approximated by a linear combination of expansion functions that satisfy the edge conditions, the latter field is determined by testing the equation of continuity of the tangential magnetic field in the slot with non-negative powers of ϕ where $|\phi|$ is the angular distance from the center of the slot.

Alternative expansion functions are introduced to preserve the accuracy of the solution in the vicintiy of an internal resonance. Containing the resonant electric field, the first alternative expansion function is normalized so that its tangential magnetic field remains finite as the resonant frequency is approached. The rest of the alternative expansion functions are orthogonal to the resonant electric field.

7. J. R. Mautz and R. F. Harrington, "Computer Program for Electromagnetic Penetration into a Conducting Circular Cylinder, TM Case," Interim Technical Report No. 7, TR-87-1, February 1987.

ABSTRACT: A computer program is described and listed. This program calculates electromagnetic penetration of a TM plane wave into the cylindrical cavity for which $\rho \leq a$ when the surface ($\rho=a$, $\phi_o \leq \phi \leq 2\pi - \phi_o$) is perfectly conducting. Here, ρ and ϕ are cylindrical coordinates. The z directed electric field E_z in the slot aperture ($\rho = a$, $-\phi_o \leq \phi \leq \phi_o$) is expressed as a linear combination of 4 even and 4 odd expansion functions. The method of moments is used to obtain the coefficients of these functions. The elements of the moment matrix are obtained by expressing each expansion function as a Fourier series in ϕ valid for ($0 \leq \phi \leq 2\pi$).

Our moment solution remains accurate when the cavity becomes resonant because alternative expansion functions were chosen to prevent the moment matrix from becoming ill-behaved. As the aperture width $2\phi_o$ decreases, more and more terms in the Fourier series are needed. Thanks to Debye's asymptotic expansions for Bessel functions, we are able to handle 10,000 terms so as to obtain accurate results for ϕ_o as small as 1.25°.

8. J. R. Mautz and R. F. Harrington, "Electromagnetic Penetration into a Conducting Circular Cylinder through a Narrow Slot, TE Case," Interim Technical Report No. 8, TR-87-4, November, 1987.

ABSTRACT: A procedure is presented for calculating the electromagnetic field in the vicinity of an infinitesimally thin conducting circular cylindrical shell with an infinitely long slot illuminated by a TE plane wave. This field is the short-circuit field plus the field due to the slot. The short-circuit field is the field that would exist if there were no slot. The field due to the slot stems from the ϕ component of the electric field in the slot. Approximated by a linear combination of expansion functions that satisfy the edge conditions, this field component is determined by testing the equation of continuity of the axial magnetic field in the slot with non-negative powers of ϕ where $|\phi|$ is the angular distance from the center of the slot.

Alternative expansion functions are introduced to preserve the accuracy of the solution in the vicinity of an internal resonance. Containing the resonant electric field, the first alternative expansion function is normalized so that its axial magnetic field remains finite as the resonant frequency is approached. The resonant electric field is that interior electric field whose ϕ component approaches zero on the closed surface consisting of the cylindrical shell and the slot as the frequency approaches the resonant frequency. The rest of the alternative expansion functions are orthogonal to the resonant electric field.

9. J. R. Mautz and R. F. Harrington, "Computer Programs for Electromagnetic Penetration into a Conducting Circular Cylinder through a Narrow Slot, TE Case," Interim Technical Report No. 9, TR-88-1, February 1988.

ABSTRACT: A computer program is described and listed. This program calculates electromagnetic penetration of a TE plane wave into the cylindrical cavity for which $\rho \leq a$ when the surface ($\rho = a$, $\phi_o \leq \phi \leq 2\pi - \phi_o$) is perfectly conducting. Here, ρ and ϕ are cylindrical coordinates. The z directed magnetic field H_z in the slot aperture ($\rho = a$, $- \phi_o \leq \phi \leq \phi_o$) is expressed as a linear combination of 4 even and 4 odd expansion functions. The method of

moments is used to obtain the coefficients of these functions. The elements of the moment matrix are obtained by expressing each expansion function as a Fourier series in ϕ valid for $(0 \leq \phi \leq 2\pi)$.

Our moment solution remains accurate when the cavity becomes resonant because alternative expansion functions were chosen to prevent the moment matrix from becoming ill-behaved. As the aperture width $2\phi_o$ decreases, more and more terms in the Fourier series are needed. Thanks to Debye's asymptotic expansions for Bessel functions, we are able to handle 10,000 terms so as to obtain accurate results for ϕ_o as small as 1.25°.

III. JOURNAL PAPERS PUBLISHED

1. E. Arvas, R. F. Harrington, and J. R. Mautz, "Radiation and Scattering from Electrically Small Conducting Bodies of Arbitrary Shape," IEEE Trans., vol. AP-34, No. 1, pp. 66-77, Jan. 1986.

ABSTRACT: A simple moment solution is given for low frequency electromagnetic scattering and radiation problems. The problem is reduced to the corresponding electrostatic and magnetostatic problems. Each static problem is solved using the Method of Moments. The surface of the perfectly conducting scatterer is modeled by a set of planar triangular patches. Pulse expansion functions and point matching testing are used to compute the charge density in the electrostatic problem. For the magnetostatic current a set of charge-free vector expansion functions is used. The problem is formulated assuming the scatter to be in an unbounded homogeneous region. Scatterers of various shapes, such as the circular disc, the sphere, and the cube are studied. Special attention is paid to a conducting box with a narrow slot. The computed results are the scattered fields, the induced charge and current distributions, and the induced electric and magnetic dipole moments. These are in close agreement with whatever published data are available.

2. E. Arvas, R. F. Harrington, J. R. Mautz, "Radiation and scattering from Electrically Small Conducting Bodies of Arbitrary Shape above an Infinite Ground Plane," IEEE Trans. on Antennas and Propagation, vol. AP-35, No. 4, pp. 378-383, April 1987.

ABSTRACT: A simple moment solution is given for the low frequency electromagnetic scattering or radiation problem involving a small perfectly conducting body of arbitrary shape placed close to an infinite ground plane. The method of images is used to account for the presence of the ground plane. The dynamic problem is approximated by two uncoupled problems, an electrostatic one and a magnetostatic one. Each static problem is then solved using the method of moments. The surface of the perfectly conducting scatterer is modeled by a set of planar triangular patches. Pulse expansion and point matching testing are used in the electrostatic problem. For the magnetostatic problem, a set of solenoidal vector expansion functions is used. The induced dipole moments are computed from the induced electrostatic charge and the magnetostatic current densities. The scattered field is the field of these induced dipoles oscillating with the frequency of the incident field. Scatterers of various shapes are studied. Special attention is given to a conducting box on the ground plane.

3. R. F. Harrington, "The Method of Moments in Electromagnetics, Journ. of Electromagnetic Waves and Applications, vol. 1, No. 3, pp. 181-200, 1987.

ABSTRACT: The method of moments is a generic name given to projective methods in which a functional equation in an infinite dimensional function space is approximated by a matrix equation in a finite dimensional subspace. Any projective method can be put into the language and notation of the method of moments, hence the concept is very general. Any linear field problem can be formulated either by differential equations (Maxwell's equations plus boundary conditions) or by integral equations (Green's functions plus superposition). Furthermore, neither the differential formulation nor the integral formulation for any particular problem is unique. The method is applied to electromagnetic scattering from conducting bodies. Computational examples are given for a sphere to illustrate a numerical implementation of the method.

4. X. Yuan, R. F. Harrington, and J. R. Mautz, "The Pseudo-Image Method for Computing the Electromagnetic Field that Penetrates into a Cavity," A.E.Ü. (Germany), Band 41, Heft 5, pp. 307-317, Sept./Oct. 1987.

ABSTRACT: A solution for electromagnetic coupling through an aperture in an arbitrarily shaped perfect conductor is obtained by the generalized network formulation for aperture problems in conjunction with a new method called the pseudo-image method. The theory developed is applied to a TM curved cylindrical surface with a narrow or a wide slot. The field in an aperture in a circular cylindrical surface is calculated by the pseudo-image method, by a method without a pseudo-image, and by EFIE method in which only an electric current is used. The aperture field calculated by the pseudo-image method is judged to be the most accurate because it agrees best with a Fourier series solution.

5. X. Yuan, R. F. Harrington, and S. S. Lee, "Electromagnetic Scattering by a Dielectric Cylinder Partially Covered by Conductors," Journal of Electromagnetic Waves and Applications, vol. 2, No. 1, pp. 21-44, 1988.

ABSTRACT: Two-dimensional electromagnetic scattering by a dielectric cylinder partially covered by zero-thickness perfect conductors is studied. The impressed field is either transverse magnetic (TM) or transverse electric (TE) to the cylinder axis. The problem is formulated in terms of two coupled boundary integral equations in each case. For the TM case the unknowns are equivalent electric currents, and for the TE case they are equivalent magnetic currents. These integral equations are solved by the method of moments with pulse functions for expansion and point matching for testing. Numerical solutions are obtained for a thin rectangular dielectric cylinder partially covered by perfectly conducting plates, where the impressed field is either a TM or a TE plane wave.

6. J. R. Mautz and R. F. Harrington, "Electromagnetic Penetration into a Conducting Circular Cylinder through a Narrow Slot, TM Case," Journal of Electromagnetic Waves and Applications, in press.

ABSTRACT: A procedure is presented for calculating the electromagnetic field in the vicinity of an infinitesimally thin conducting circular cylindrical

shell with an infinitely long slot illuminated by a TM plane wave. This field is the short-circuit field plus the field due to the slot. The short-circuit field is the field that would exist if there were no slot. The field due to the slot stems from the axial electric field in the slot. Approximated by a linear combination of expansion functions that satisfy the edge conditions, the latter field is determined by testing the equation of continuity of the tangential magnetic field in the slot with non-negative powers of ϕ where $|\phi|$ is the angular distance from the center of the slot.

Alternative expansion functions are introduced to preserve the accuracy of the solution in the vicinity of an internal resonance. Containing the resonant electric field, the first alternative expansion function is normalized so that its tangential magnetic field remains finite as the resonant frequency is approached. The rest of the alternative expansion functions are orthogonal to the resonant electric field.

IV. ORAL PAPERS

1. R. F. Harrington, "Admittance of Apertures in Bodies of Finite Extent," URSI North American Radio Science Meeting, Vancouver, Canada, June 1985. Abstracts, p. 202.

2. R. F. Harrington, "The Method of Moments in Electromagnetics," 1986 National Radio Science Meeting, Philadelphia, PA, June 1986. Abstracts, p. 224.

3. X. Yuan and R. F. Harrington, "A Combined-Source Formulation for Electromagnetic Scattering by a Dielectric-Filled Conducting Cylinder with an Aperture," URSI Radio Science Meeting, Blacksburg, VA, June 15-19, 1987. Abstracts, p. 223.

4. R. F. Harrington, "Boundary Integral Formulations, Existence and Uniqueness of Solutions," URSI Radio Science Meeting, Blacksburg, VA, June 1987. Abstracts, p. 210.

5. R. F. Harrington and E. Arvas, "Boundary Integral Equations for Dielectric Bodiens," URSI XXII General Assembly, Tel Aviv, Israel, August 1987. Abstracts, p. 256.

V. SCIENTIFIC PERSONNEL SUPPORTED BY THIS CONTRACT

1. Roger F. Harrington, Principal Investigator.

2. Joseph R. Mautz, Research Associate.

3. Xingchao Yuan, Graduate Assistant. Awarded Ph.D. degree, December 1987.

4. Dhimant Master, Graduate Assistant.

5. Stilianos Papatheodorou, Graduate Assistant.

END
DATE
FILMED
5-88
DTIC